EXHIBIT W

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Shampine et al.

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(54) **METHOD OF PUMPING AN OILFIELD FLUID AND SPLIT STREAM OILFIELD PUMPING SYSTEMS**

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(22) Filed: **May 29, 2007**

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Related U.S. Application Data

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E21B 43/04 (2006.01)
E21B 43/267 (2006.01)

(52) **U.S. Cl.** **166/369**; 166/308.1; 166/68.5; 166/105; 415/199.1

(58) **Field of Classification Search** 166/369, 166/308.1, 68, 68.5, 105; 415/199.1, 199.6, 415/199.2; 366/160.2
See application file for complete search history.

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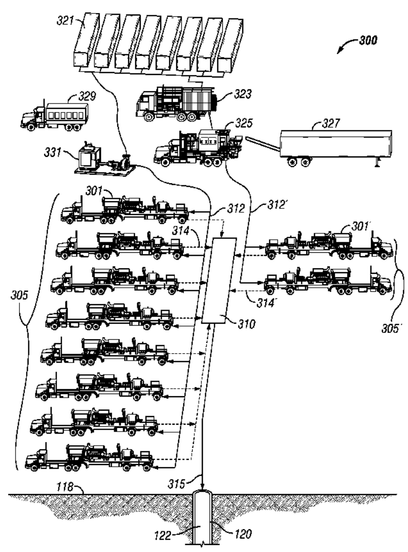
(57) **ABSTRACT**

A method of pumping an oilfield fluid from a well surface to a wellbore is provided that includes providing a clean stream; operating one or more clean pumps to pump the clean stream from the well surface to the wellbore; providing a dirty stream including a solid material disposed in a fluid carrier; and operating one or more dirty pumps to pump the dirty stream from the well surface to the wellbore, wherein the clean stream and the dirty stream together form the oilfield fluid.

31 Claims, 9 Drawing Sheets



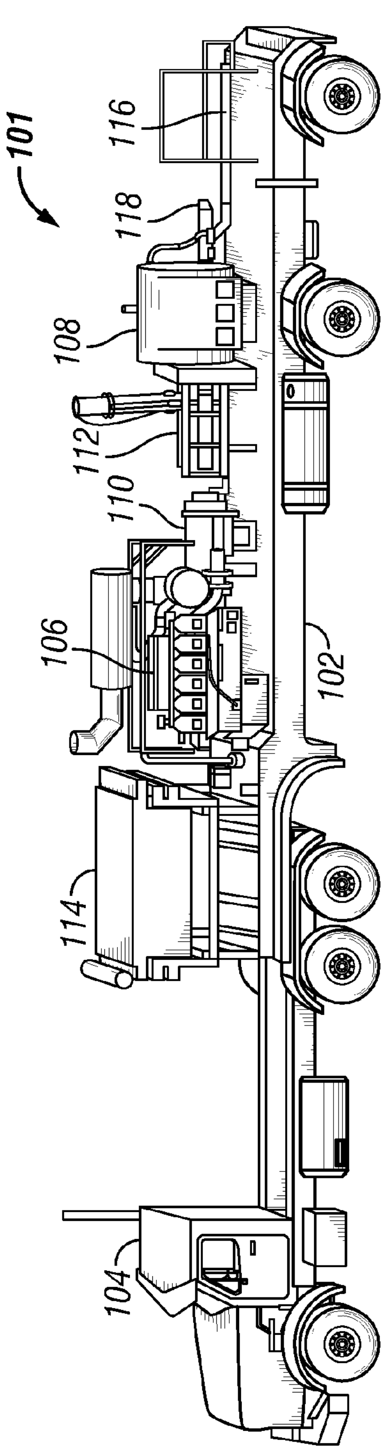

101
116
118
108
112
110
106
102
114
104

FIG. 1

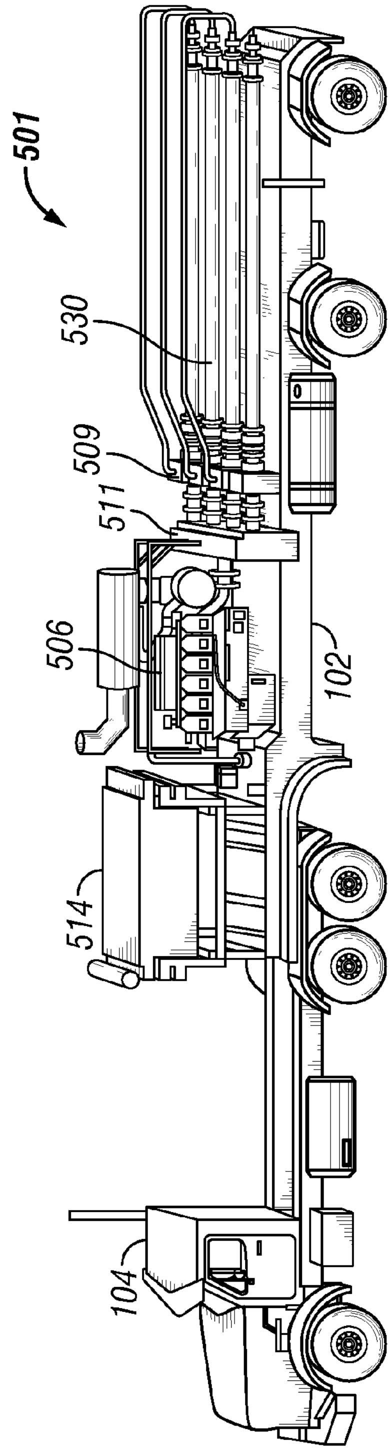

501
530
509
511
506
102
514
104

FIG. 6

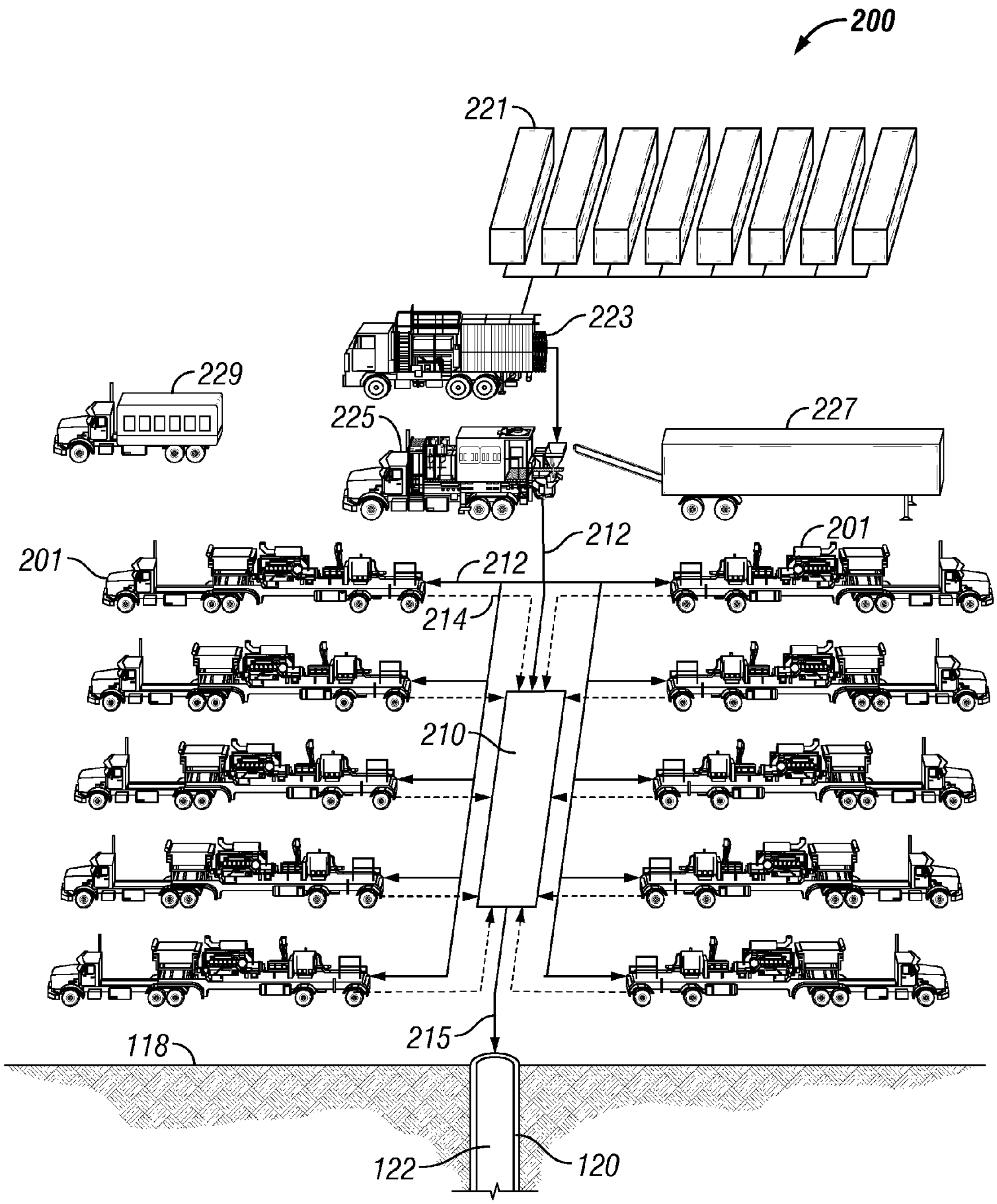
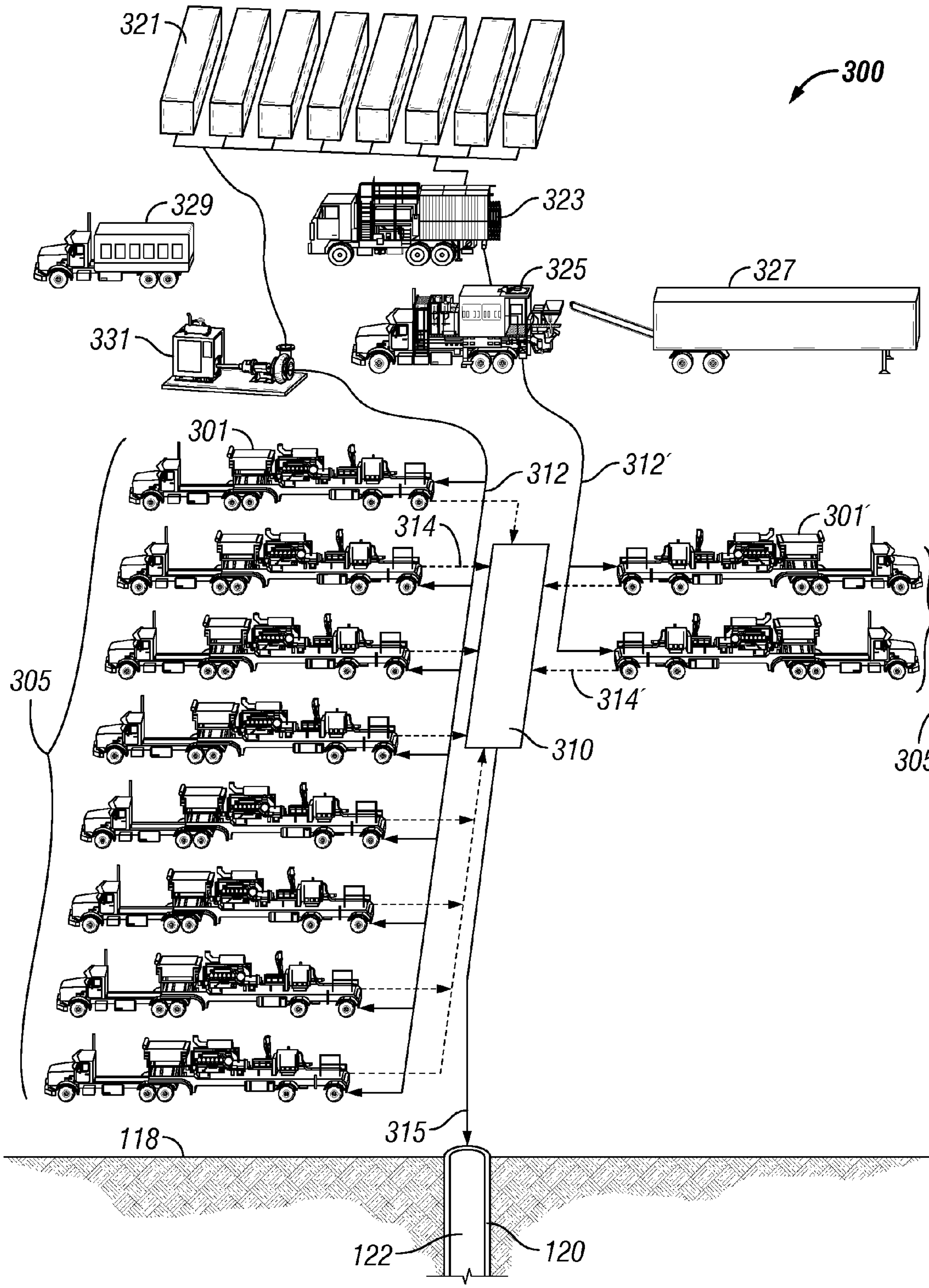


FIG. 2
(Prior Art)



321
300
329
323
325
327
331
301
312
312′
314
301′
305
314′
310
305′
315
118
122
120

FIG. 3

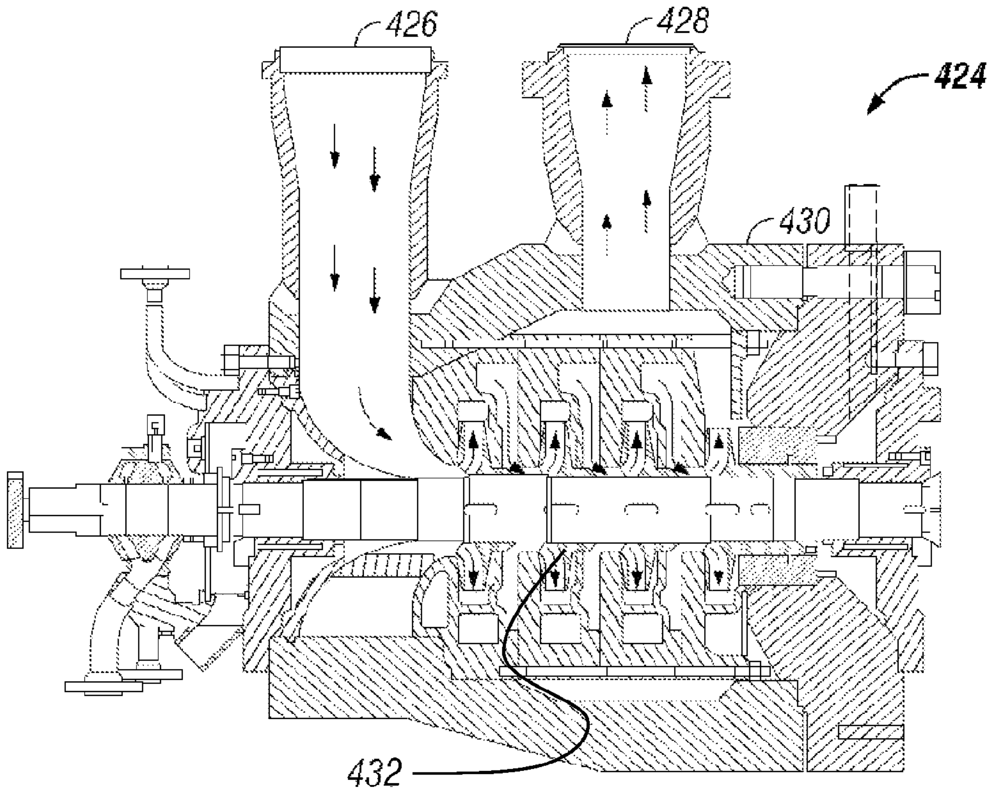


FIG. 4

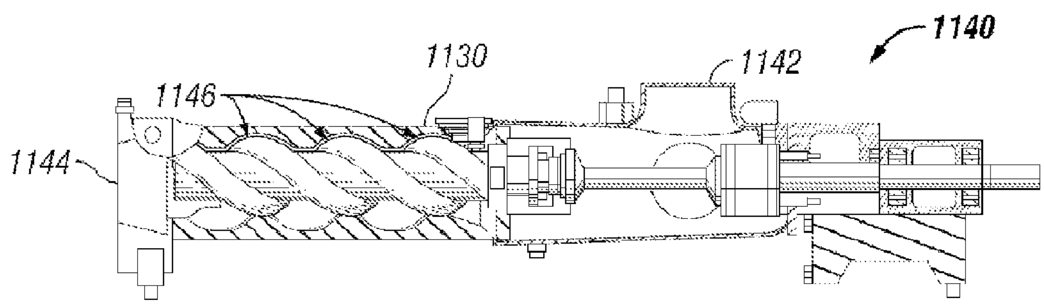
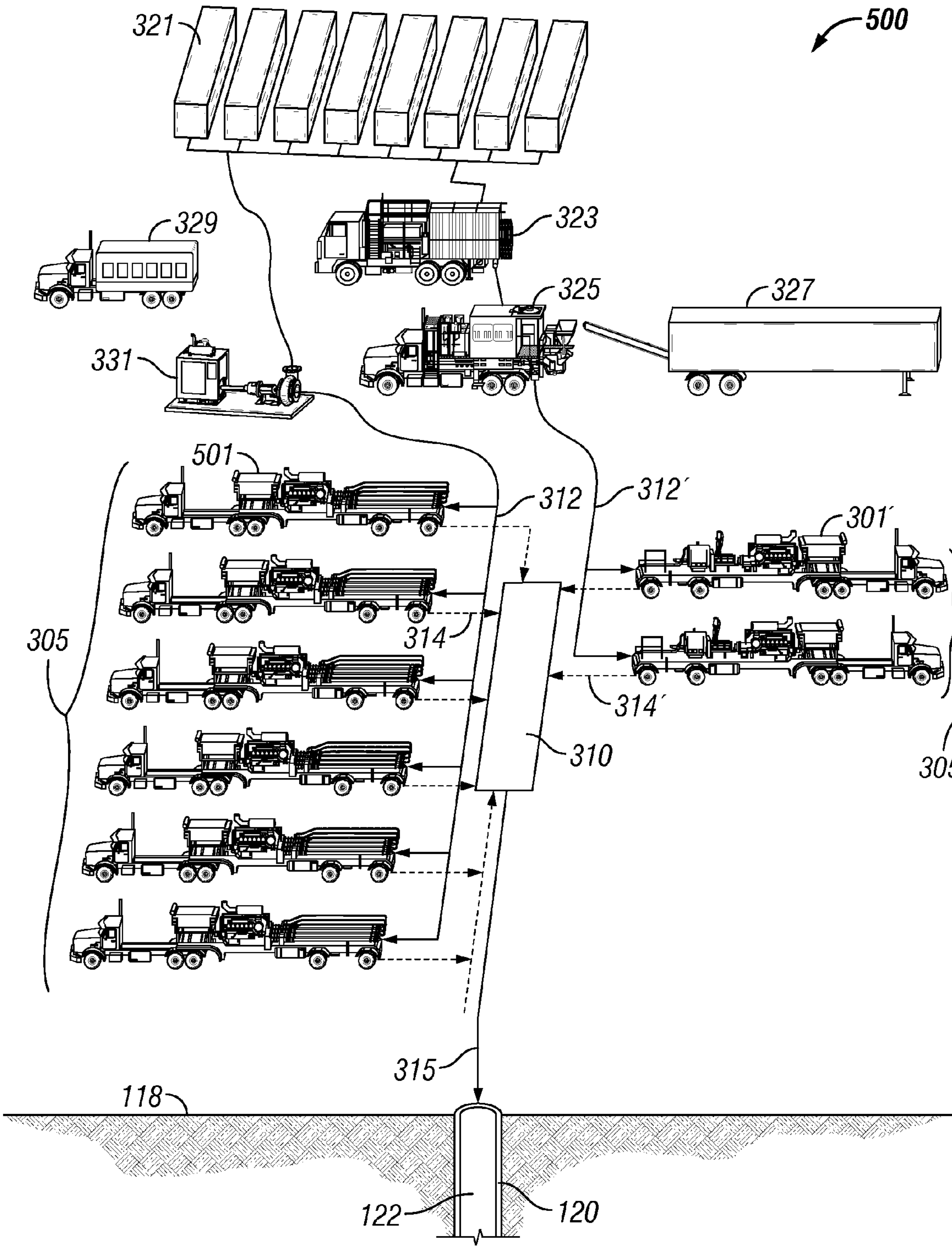


FIG. 11



500
321
329
323
325
327
331
501
312
312′
301′
305
314
314′
310
305′
315
118
122
120

FIG. 5

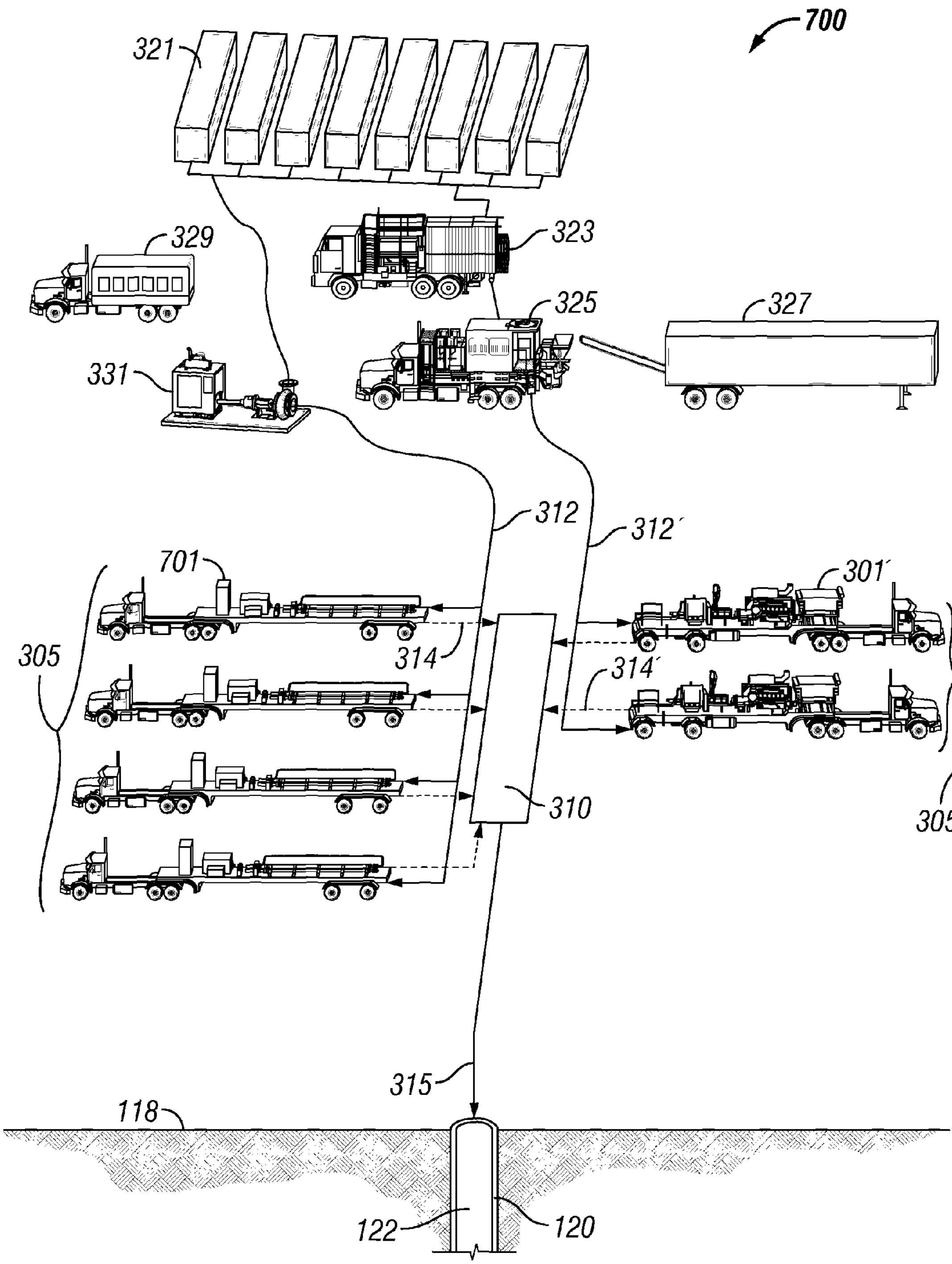

700
321
323
329
325
327
331
312
312´
701
301´
305
314
314´
310
305´
315
118
122
120

FIG. 7

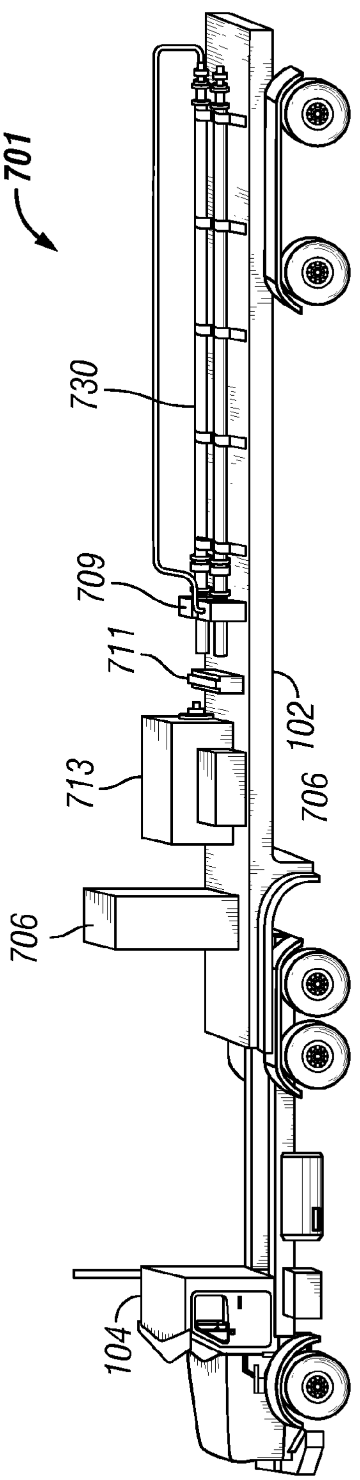


FIG. 8

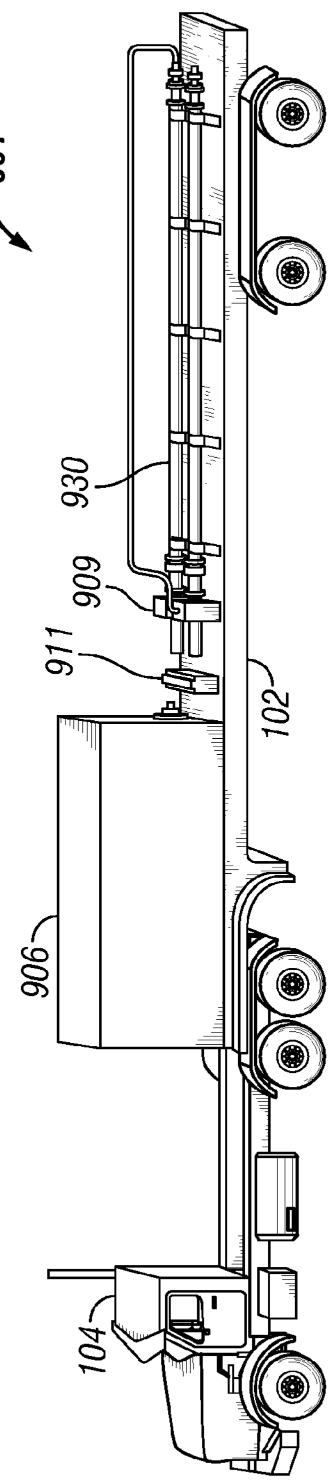
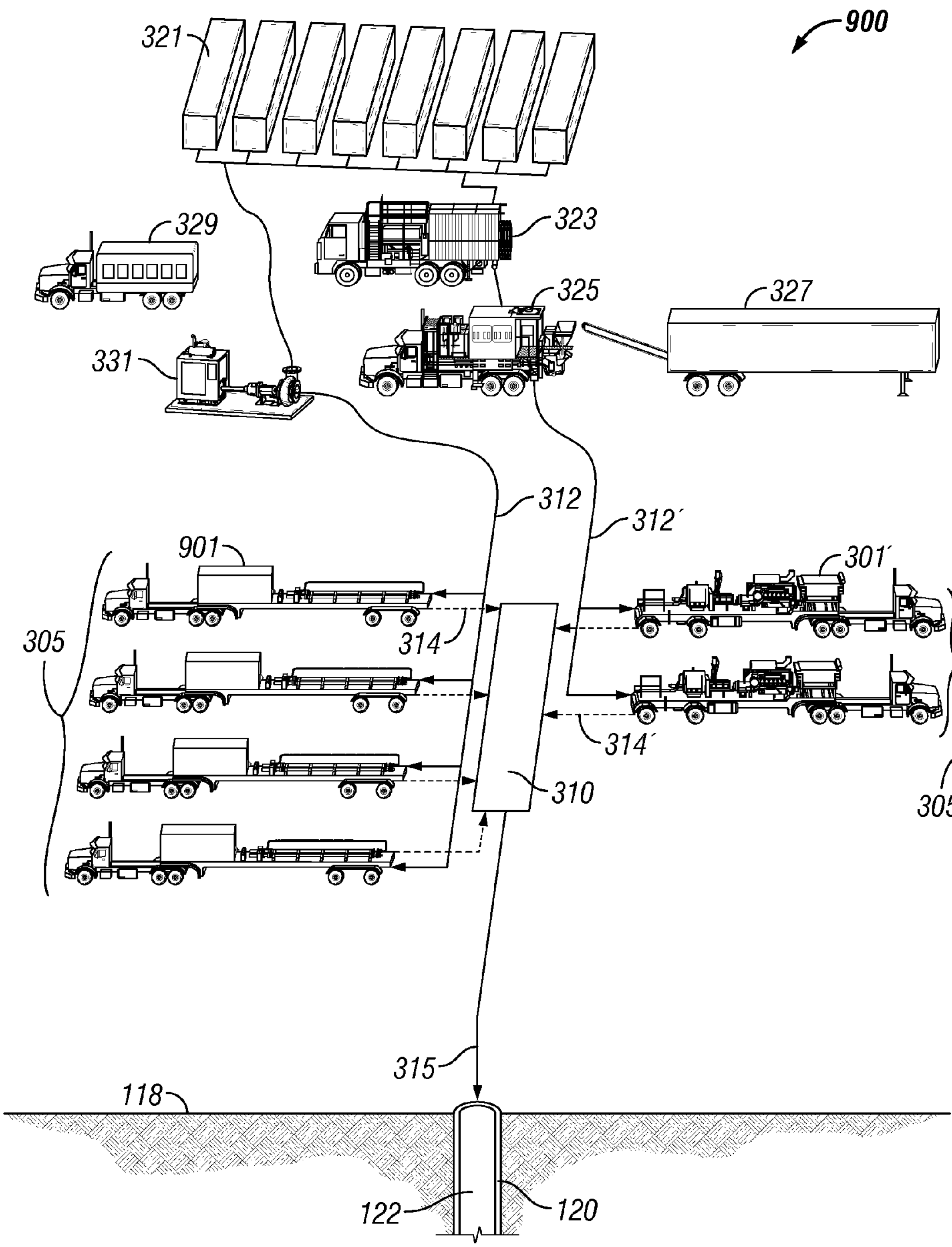
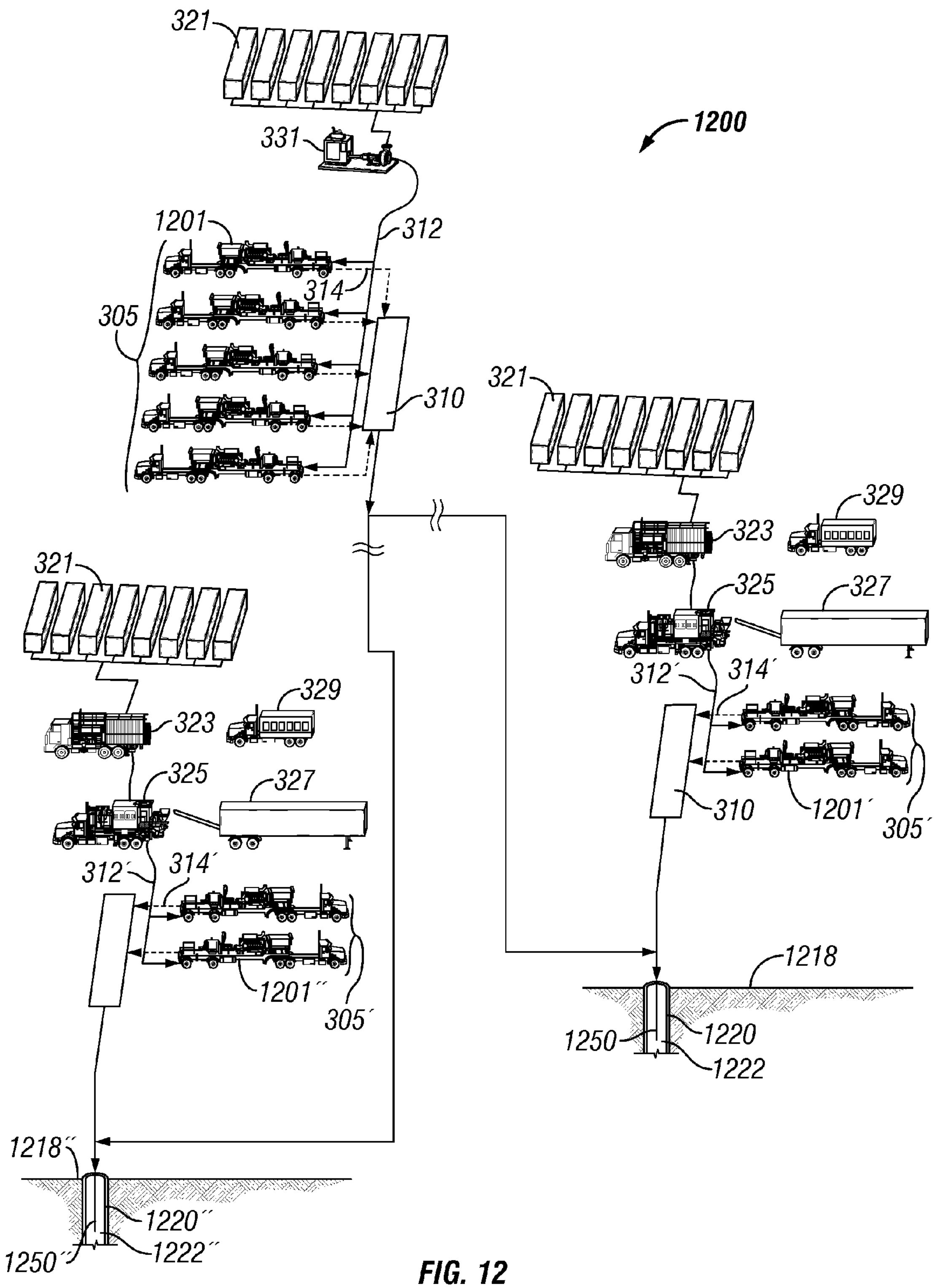


FIG. 10



900
321
329
323
325
327
331
312
312´
901
301´
305
314
314´
310
305´
315
118
122
120

FIG. 9



321
1200
331
1201
312
314
305
310
321
329
323
325
327
312´
314´
1201´
305´
310
321
329
323
325
327
312´
314´
1201´´
305´
1218
1250
1220
1222
1218´´
1220´´
1222´´
1250´´

FIG. 12

METHOD OF PUMPING AN OILFIELD FLUID AND SPLIT STREAM OILFIELD PUMPING SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority under 35 U.S.C. §119(e) to U.S. Provisional Application Ser. No. 60/803,798, filed on Jun. 2, 2006, which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to a pumping system for pumping a fluid from a surface of a well to a wellbore at high pressure, and more particularly to a such a system that includes splitting the fluid into a clean stream having a minimal amount of solids and a dirty stream having solids in a fluid carrier.

BACKGROUND

In special oilfield applications, pump assemblies are used to pump a fluid from the surface of the well to a wellbore at extremely high pressures. Such applications include hydraulic fracturing, cementing, and pumping through coiled tubing, among other applications. In the example of a hydraulic fracturing operation, a multi-pump assembly is often employed to direct an abrasive containing fluid, or fracturing fluid, through a wellbore and into targeted regions of the wellbore to create side "fractures" in the wellbore. To create such fractures, the fracturing fluid is pumped at extremely high pressures, sometimes in the range of 10,000 to 15,000 psi or more. In addition, the fracturing fluid contains an abrasive proppant which both facilitates an initial creation of the fracture and serves to keep the fracture "propped" open after the creation of the fracture. These fractures provide additional pathways for underground oil and gas deposits to flow from underground formations to the surface of the well. These additional pathways serve to enhance the production of the well.

Plunger pumps are typically employed for high pressure oilfield pumping applications, such as hydraulic fracturing operations. Such plunger pumps are sometimes also referred to as positive displacement pumps, intermittent duty pumps, triplex pumps or quintuplex pumps. Plunger pumps typically include one or more plungers driven by a crankshaft toward and away from a chamber in a pressure housing (typically referred to as a "fluid end") in order to create pressure oscillations of high and low pressures in the chamber. These pressure oscillations allow the pump to receive a fluid at a low pressure and discharge it at a high pressure via one way valves (also called check valves).

Multiple plunger pumps are often employed simultaneously in large scale hydraulic fracturing operations. These pumps may be linked to one another through a common manifold, which mechanically collects and distributes the combined output of the individual pumps. For example, hydraulic fracturing operations often proceed in this manner with perhaps as many as twenty plunger pumps or more coupled together through a common manifold. A centralized computer system may be employed to direct the entire system for the duration of the operation.

However, the abrasive nature of fracturing fluids is not only effective in breaking up underground rock formations to create fractures therein, it also tends to wear out the internal components of the plunger pumps that are used to pump it.

Thus, when plunger pumps are used to pump fracturing fluids, the repair, replacement and/or maintenance expenses for the internal components of the pumps are extremely high, and the overall life expectancy of the pumps is low.

For example, when a plunger pump is used to pump a fracturing fluid, the pump fluid end, valves, valve seats, packings, and plungers require frequent maintenance and/or replacement. Such a replacement of the fluid end is extremely expensive, not only because the fluid end itself is expensive, but also due to the difficulty and timeliness required to perform the replacement. Valves, on the other hand are relatively inexpensive and relatively easy to replace, but require such frequent replacements that they comprise a large percentage of plunger pump maintenance expenses. In addition, when a valve fails, the valve seat is often damaged as well, and seats are much more difficult to replace than valves due to the very large forces required to pull them out of the fluid end. Accordingly, a need exists for an improved system and method of pumping fluids from a well surface to a wellbore.

SUMMARY

In one embodiment, the present invention includes splitting a fracturing fluid stream into a clean stream having a minimal amount of solids and a dirty stream having solids in a fluid carrier, wherein the clean stream is pumped from the well surface to a wellbore by one or more clean pumps and the dirty stream is pumped from the well surface to a wellbore by one or more dirty pumps, thus greatly increasing the useful life of the clean pumps.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIG. **1** is side view of a plunger pump for use in a pump system according to one embodiment of the present invention;

FIG. **2** is a schematic representation of a pump system for performing a hydraulic fracturing operation on a well according to one embodiment of the prior art;

FIG. **3** is a schematic representation of a pump system for pumping a fluid from a well surface to a wellbore according to one embodiment of the present invention, wherein the fluid is split into a clean stream, pumped by one or more plunger pumps and a dirty stream also pumped by one or more plunger pumps;

FIG. **4** is a side cross-sectional view of a multistage centrifugal pump;

FIGS. **5**, **7**, and **9** each show a schematic representation of a pump system for pumping a fluid from a well surface to a wellbore according to one embodiment of the present invention, wherein the fluid is split into a clean stream, pumped by one or more multistage centrifugal pumps, and a dirty stream pumped by one or more plunger pumps;

FIGS. **6**, **8** and **10** each show a top perspective view of a multistage centrifugal pump for use in a pump system according to one embodiment of the present invention;

FIG. **11** is a side cross-sectional view of a progressing cavity pump; and

FIG. **12** is a schematic representation of a pump system for pumping a fluid from a well surface to a wellbore according to one embodiment of the present invention, wherein the fluid is

split into a clean stream pumped by one or more clean pumps that are remotely located from the wellbore, and a dirty stream.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Embodiments of the present invention relate generally to a pumping system for pumping a fluid from a surface of a well to a wellbore at high pressures, and more particularly to such a system that includes splitting the fluid into a clean stream having a minimal amount of solids and a dirty stream having solids in a fluid carrier. In one embodiment, both the clean stream and the dirty stream are pumped by the same type of pump. For example, in one embodiment one or more plunger pumps are used to pump each fluid stream. In another embodiment, the clean stream and the dirty stream are pumped by different types of pumps. For example, in one embodiment one or more plunger pumps are used to pump the dirty stream and one or more horizontal pumps (such as a centrifugal pump or a progressive cavity pump) are used to pump the clean fluid stream.

FIG. **1** shows a plunger pump **101** for pumping a fluid from a well surface to a wellbore. As shown, the plunger pump **101** is mounted on a standard trailer **102** for ease of transportation by a tractor **104**. The plunger pump **101** includes a prime mover **106** that drives a crankshaft through a transmission **110** and a drive shaft **112**. The crankshaft, in turn, drives one or more plungers toward and away from a chamber in the pump fluid end **108** in order to create pressure oscillations of high and low pressures in the chamber. These pressure oscillations allow the pump to receive a fluid at a low pressure and discharge it at a high pressure via one way valves (also called check valves). Also connected to the prime mover **106** is a radiator **114** for cooling the prime mover **106**. In addition, the plunger pump fluid end **108** includes an intake pipe **116** for receiving fluid at a low pressure and a discharge pipe **118** for discharging fluid at a high pressure.

FIG. **2** shows an prior art pump system **200** for pumping a fluid from a surface **118** of a well **120** to a wellbore **122** during an oilfield operation. In this particular example, the operation is a hydraulic fracturing operation, and hence the fluid pumped is a fracturing fluid. As shown, the pump system **200** includes a plurality of water tanks **221**, which feed water to a gel maker **223**. The gel maker **223** combines water from the tanks **221** with a gelling agent to form a gel. The gel is then sent to a blender **225** where it is mixed with a proppant from a proppant feeder **227** to form a fracturing fluid. The gelling agent increases the viscosity of the fracturing fluid and allows the proppant to be suspended in the fracturing fluid. It may also act as a friction reducing agent to allow higher pump rates with less frictional pressure.

The fracturing fluid is then pumped at low pressure (for example, around 60 to 120 psi) from the blender **225** to a plurality of plunger pumps **201** as shown by solid lines **212**. Note that each plunger pump **201** in the embodiment of FIG. **2** may have the same or a similar configuration as the plunger pump **101** shown in FIG. **1**. As shown in FIG. **2**, each plunger pump **201** receives the fracturing fluid at a low pressure and discharges it to a common manifold **210** (sometimes called a missile trailer or missile) at a high pressure as shown by dashed lines **214**. The missile **210** then directs the fracturing fluid from the plunger pumps **201** to the wellbore **122** as shown by solid line **215**.

In a typical hydraulic fracturing operation, an estimate of the well pressure and the flow rate required to create the desired side fractures in the wellbore is calculated. Based on this calculation, the amount of hydraulic horsepower needed from the pumping system in order to carry out the fracturing operation is determined. For example, if it is estimated that the well pressure and the required flow rate are 6000 psi (pounds per square inch) and 68 BPM (Barrels Per Minute), then the pump system **200** would need to supply 10,000 hydraulic horsepower to the fracturing fluid (i.e., 6000*68/40.8).

In one embodiment, the prime mover **106** in each plunger pump **201** is an engine with a maximum rating of 2250 brake horsepower, which, when accounting for losses (typically about 3% for plunger pumps in hydraulic fracturing operations), allows each plunger pump **201** to supply a maximum of about 2182 hydraulic horsepower to the fracturing fluid. Therefore, in order to supply 10,000 hydraulic horsepower to a fracturing fluid, the pump system **200** of FIG. **2** would require at least five plunger pumps **201**.

However, in order to prevent an overload of the transmission **110**, between the engine **106** and the fluid end **108** of each plunger pump **201**, each plunger pump **201** is normally operated well under is maximum operating capacity. Operating the pumps under their operating capacity also allows for one pump to fail and the remaining pumps to be run at a higher speed in order to make up for the absence of the failed pump.

As such in the example of a fracturing operation requiring 10,000 hydraulic horsepower, bringing ten plunger pumps **201** to the wellsite enables each pump engine **106** to be operated at about 1030 brake horsepower (about half of its maximum) in order to supply 1000 hydraulic horsepower individually and 10,000 hydraulic horsepower collectively to the fracturing fluid. On the other hand, if only nine pumps **201** are brought to the wellsite, or if one of the pumps fails, then each of the nine pump engines **106** would be operated at about 1145 brake horsepower in order to supply the required 10,000 hydraulic horsepower to the fracturing fluid. As shown, a computerized control system **229** may be employed to direct the entire pump system **200** for the duration of the fracturing operation.

As discussed above, a problem with this pump system **200** is that each plunger pump **201** is exposed to the abrasive proppant of the fracturing fluid. Typically the concentration of the proppant in the fracturing fluid is about 2 to 12 pounds per gallon. As mentioned above, the proppant is extremely destructive to the internal components of the plunger pumps **201** and causes the useful life of these pumps **201** to be relatively short.

In response to the problems of the above pump system **200**, FIG. **3** shows a pump system **300** according to one embodiment of the present invention. In such an embodiment, the fluid that is pumped from the well surface **118** to the wellbore **122** is split into a clean side **305** containing primarily water that is pumped by one or more clean pumps **301**, and a dirty side **305'** containing solids in a fluid carrier that is pumped by one or more dirty pumps **301'**. For example, in a fracturing operation the dirty side **305'** contains a proppant in a fluid carrier (such as a gel). As is explained in detail below, such a pump system **300** greatly increases the useful life of the clean pumps **301**, as the clean pumps **301** are not exposed to abrasive fluids. Note that each clean pump **301** and each dirty pump **301'** in the embodiment of FIG. **3** may have the same or a similar configuration as the plunger pump **101** shown in FIG. **1**.

In the pump system **300** of FIG. **3**, the dirty pumps **301'** receive a dirty fluid in a similar manner to that described with respect to FIG. **2**. That is, in the embodiment of FIG. **3**, the pump system **300** includes a plurality of water tanks **321**, which feed water to a gel maker **323**. The gel maker **323**

combines water from the tanks **321** with a gelling agent and forms a gel, which is sent to a blender **325** where it is mixed with a proppant from a proppant feeder **327** to form a dirty fluid, in this case a fracturing fluid. Exemplary proppants include sand grains, resin-coated sand grains, polylactic acids, or high-strength ceramic materials such as sintered bauxite, among other appropriate proppants.

The dirty fluid is then pumped at low pressure (for example, around 60-120 psi) from the blender **325** to the dirty pumps **301'** as shown by solid lines **312'**, and discharged by the dirty pumps **301'** at a high pressure to a common manifold or missile **310** as shown by dashed lines **314'**.

On the clean side **305**, water from the water tanks **321** is pumped at low pressure (for example, around 60-120 psi) directly to the clean pumps **301** by a transfer pump **331** as shown by solid lines **312**, and discharged at a high pressure to the missile **310** as shown by dashed lines **314**. The missile **310** receives both the clean and dirty fluids and directs their combination, which forms a fracturing fluid, to the wellbore **122** as shown by solid line **315**.

If the pump system **300** shown in FIG. **3** were used in place of the pump system **200** shown in FIG. **2** (that is, in a well **120** requiring 10,000 hydraulic horsepower), and assuming that each clean pump **301** and each dirty pump **301'** contains an engine **106** with a maximum rating of 2250 brake horsepower, then as in the pump system **200** of FIG. **2**, each pump engine **106** in each clean and dirty pump **301/301'** could be operated at about 1030 brake horsepower in order to supply the required 10,000 hydraulic horsepower to the fracturing fluid. Also, as with the pump system **200** of FIG. **2**, the number of total number of pumps **301/301'** in the pump system **300** of FIG. **3** may be reduced if the pump engines **106** are run at a higher brake horsepower. For example, if one of the pumps fail on either the clean side **305** or the dirty side **305'**, then the remaining pumps may be run at a higher speed in order to make up for the absence of the failed pump. In addition, a computerized control system **329** may be employed to direct the entire pump system **300** for the duration of the fracturing operation.

With the pump system **300** of FIG. **3**, the clean pumps **301** are not exposed proppants. As a result, it is estimated that the clean pumps **301** in the pump system **300** of FIG. **3** will have a useful life of about ten times the useful life of the pumps **201** in the pump system **200** of FIG. **2**. However, in order to compensate for the fact that the fluid received and discharged from the clean pumps **301** lacks proppant, the dirty pumps **301'** in the pump system **300** of FIG. **3** are exposed to a greater concentration of proppant in order to obtain the same results as the pump system **200** of FIG. **2**. That is, in an operation requiring a fracturing fluid with a proppant concentration of about 2 pounds per gallon to be pumped through the pumps **201** in FIG. **2**, the dirty pumps **301'** in the pump system **300** of FIG. **3** would need to pump a fracturing fluid with a proppant concentration of about 10 pounds per gallon. As a result, it is estimated that the useful life of the pumps **301'** on the dirty side **305'** of the pump system **300** of FIG. **3** would be about ⅕th the useful life of the pumps **201** in the pump system **200** of FIG. **2**.

However, comparing the pump systems **200/300** from FIGS. **2** and **3**, and assuming the use of the same total number of pumps in each pump system **200/300** for pumping the same concentration of proppant at the same hydraulic horsepower, the eight clean pumps **301** in the pump system **300** of FIG. **3** having a useful life of about ten times as long as the pumps **201** in the pump system **200** of FIG. **2**, far outweighs the useful life of the two dirty pumps **301'** in the pump system **300** of FIG. **3** being about ⅕th as long as the pumps **201** in the pump system **200** of FIG. **2**. As such, the overall useful life of the pump system **300** of FIG. **3** is much greater than that of the pump system **200** of FIG. **2**.

Note that it was assumed that the pump system **300** of FIG. **3** was used on a well **120** requiring 10,000 hydraulic horsepower. This was assumed merely to form a direct comparison of how the pump system **300** of FIG. **3** would perform versus how the pump system **200** of FIG. **2** would perform when acting on the same well **120**. This same 10,000 hydraulic horsepower well requirement will be assumed for the pump systems **500/700/900** (described below) for the same comparative purpose. However, as described further below, it is to be understood that each of the pump systems described herein **300/500/700/900/1200** may supply any desired amount of hydraulic horsepower to a well. For example, various wells might have hydraulic horsepower requirements in the range of about 500 hydraulic horsepower to about 100,000 hydraulic horsepower, or even more.

As such, although FIG. **3** shows the pump system **300** as having eight dirty pumps **301'** and two clean pumps **301**, in alternative embodiments the pump system **300** may contain any appropriate number of dirty pumps **301'**, and any appropriate number of clean pumps **301**, dependent on the hydraulic horsepower required by the well **120**, the percent capacity at which it is desired to run the pump engines **106**, and the amount of proppant desired to be pumped.

Also note that although two dirty pumps **301'** are shown in the embodiment of FIG. **3**, the pump system **300** may contain more or even less than two dirty pumps **301'**, the trade off being that the less dirty pumps **301'** the pump system **300** has, the higher the concentration of proppant that must be pumped by each dirty pump **301'**; the result of the higher concentration of proppant being the expedited deterioration of the useful life of the dirty pumps **301'**. On the other hand, the fewer the dirty pumps **301'**, the more clean pumps **301** that can be used to obtain the same results, and as mentioned above, the expedited deterioration of the useful life of the dirty pumps **301'** is far outweighed by the increased useful life of the clean pumps **301**.

In the embodiment of FIG. **3**, two dirty pumps **301'** are shown. Although the pump system **300** could work with only one dirty pump **301'**, in this embodiment the pump system **300** includes two dirty pumps **301'** so that if one of the dirty pumps fails, the proppant concentration in the remaining dirty pump can be doubled to make up for the absence of the failed dirty side pump.

Although the pump system **300** of FIG. **3** achieves the goal of having a longer overall useful life than the pump system **200** of FIG. **2**, the pump system **300** of FIG. **3** still uses plunger pumps. Although this is a perfectly acceptable embodiment, a problem with plunger pumps is that they continually oscillate between high pressure operating conditions and low pressure operating conditions. That is, when a plunger is moved away from its fluid end, the fluid end experiences a low pressure; and when a plunger is moved toward its fluid end, the fluid end experiences a high pressure. This oscillating pressure on the fluid end places the fluid end (as well as it internal components) under a tremendous amount of strain which eventually results in fatigue failures in the fluid end.

In addition, plunger pumps generate torque pulsations and pressure pulsations, these pulsations being proportional to the number of plungers in the pump, with the higher the number of plungers, the lower the pulsations. However, increasing the number of plungers comes at a significant cost in terms of mechanical complexity and increased cost to replace the valves, valve seats, packings, plungers, etc. On the other

hand, the pulsations created by plunger pumps are the main cause of transmission **110** failures, which fail fairly frequently, and the transmission **110** is even more difficult to replace than the pump fluid end **108** and is comparable in cost.

The pressure pulses in plunger pumps are large enough that if the high pressure pump system goes into resonance, parts of the pumping system will fail in the course of a single job. That is, components such as the missile or treating iron can fail catastrophically. This pressure pulse problem is even worse when multiple pumps are run at the same or very similar speeds. As such, in a system using multiple plunger pumps, considerable effort has to be devoted to running all of the pumps at different speeds to prevent resonance, and the potential for catastrophic failure.

Multistage centrifugal pumps, on the other hand, can receive fluid at a low pressure and discharge it at a high pressure while exposing its internal components to a fairly constant pressure with minimal variation at each stage along its length. The lack of large pressure variations means that the pressure housing of the centrifugal pump does not experience significant fatigue damage while pumping. As a result, when pumping clean fluids, multistage centrifugal pump systems generally exhibit higher life expectancy, and lower operational costs than plunger pumps. In addition, multistage centrifugal pump systems also tend to wear out and lose efficiency gradually, rather than failing catastrophically as is more typical with plunger pumps and their associated transmissions. Therefore, in some situations when pumping a clean fluid it may be desired to use multistage centrifugal pumps rather than plunger pumps.

FIG. **4** shows an example of a multistage centrifugal pump **424**. As shown, the multistage centrifugal pump **424** receives a fluid through an intake pipe **426** at a low pressure and discharges it through a discharge pipe **428** at a high pressure by passing the fluid (as shown by the arrows) along a long cylindrical pipe or barrel **430** having a series of impellers or rotors **432**. That is, as the fluid is propelled by each successive impeller **432**, it gains more and more pressure until it exits the pump at a much higher pressure than it entered. To create a multistage centrifugal pump with a greater pressure output, the diameter of the impellers **432** may be increased and/or the number of impellers **432** (also referred to as the number of stages of the pump) may be increased.

As such it may be desirable to create a pumping system similar to that of FIG. **3**, but using multistage centrifugal pumps as the clean pumps rather than plunger pumps as the clean pumps. Such a configuration in shown in the pump system **500** of FIG. **5**. Note that many portions of the pump system **500** of FIG. **5** may generally operate in the same manner as described above with respect to the pump system **300** of FIG. **3**. Therefore, the operations of the pump system **500** of FIG. **5** that are similar to the operations described above with respect to the pump system **300** of FIG. **3** are not repeated here to avoid duplicity. However, as mentioned above, a difference between the pump system **500** of FIG. **5** and the pump system **300** of FIG. **3** is that the clean pumps **501** on the clean side **305** of the pump system **500** of FIG. **5** are multistage centrifugal pumps rather than plunger pumps.

In this embodiment, each clean pump **501** may have the same or a similar configuration as the multistage centrifugal pump **501** shown in FIG. **6**. As shown in FIG. **6**, the multistage centrifugal pump **501** is mounted on a standard trailer **102** for ease of transportation by a tractor **104**. The multistage centrifugal pump **501** includes a prime mover **506** that drives the impellers contained therein through a gearbox **511**. Also connected to the prime mover **506** is a radiator **514** for cooling the prime mover **506**. In addition, the multistage centrifugal pump **501** includes four centrifugal pump barrels **530** connected in series by a high pressure interconnecting manifold **509**. In this embodiment, each pump barrel **530** contains forty impellers having a diameter of approximately 5-11 inches. An example of such a pump barrel **530** is commercially available from Reda Pump Co. of Singapore (i.e., a Reda 675 series HPS pump barrel with 40 stages.)

In one embodiment, the prime mover **506** in each multistage centrifugal pump **501** in the pump system **500** of FIG. **5** is a diesel engine with a maximum rating of 2250 brake horsepower, which when accounting for losses (typically about 30% for multistage centrifugal pumps in hydraulic fracturing operations), allows each clean pump **501** in the pump system **500** of FIG. **5** to supply a maximum of about 1575 hydraulic horsepower to the fracturing fluid. Therefore, in order to supply 10,000 hydraulic horsepower to a fracturing fluid, assuming each dirty pump **301'** supplies about 1000 hydraulic horsepower to the fracturing fluid (as assumed in the pump systems **200** and **300** of FIGS. **2** and **3**), the pump system **500** of FIG. **5** would require six multistage centrifugal pump **501**, each supplying 1575 hydraulic horsepower to obtain a total of about 11,450 hydraulic horsepower.

Note that the excess available 1,450 hydraulic horsepower over the required 10,000 hydraulic horsepower allows one of the pumps **501/301'** in the pump system **500** of FIG. **5** to fail with the remaining pumps **501/301'** making up for the absence of the failed pump, and/or allows the clean pumps **501** to operate at less than full power. Note, however, that since the multistage centrifugal pumps **501** of FIG. **5** do not contain a transmission, they can be run at full power without fear of failure. As such, in order for the pump system **500** of FIG. **5** to pump the same concentration of proppant at the same hydraulic horsepower as the pump system **200** of FIG. **2**, two less total pumps are required. In addition, the clean pumps **501** in the pump system **500** of FIG. **5** are likely to last longer than the pumps **201** in the pump system **200** of FIG. **2**.

FIG. **7** shows an embodiment similar to that shown in FIG. **5**, but with differently configured clean pumps **701**. Note that many portions of the pump system **700** of FIG. **7** may generally operate in the same manner as described above with respect to the pump system **300** of FIG. **3**. Therefore, the operations of the pump system **700** of FIG. **7** that are similar to the operations described above with respect to the pump system **300** of FIG. **3** are not repeated here to avoid duplicity. However, as mentioned above, a difference between the pump system **700** of FIG. **7** and the pump system **300** of FIG. **3** is that the clean pumps **701** on the clean side **305** of the pump system **700** of FIG. **7** are multistage centrifugal pumps rather than plunger pumps. In addition, although the clean pumps **501/701** in the pump systems **500/700** of both FIGS. **5** and **7** are multistage centrifugal pumps, the multistage centrifugal pumps in the pump system **700** of FIG. **7** are configured differently than the multistage centrifugal pumps of FIG. **5**.

For example, in the embodiment of FIG. **7**, each clean pump **701** may have the same or a similar configuration as the multistage centrifugal pump **701** shown in FIG. **8**. As shown in FIG. **8**, the multistage centrifugal pump **701** is mounted on a standard trailer **102** for ease of transportation by a tractor **104**. The multistage centrifugal pump **701** includes a prime mover **706** that drives the impellers contained therein through a gearbox **711** and a transfer box **713**. In addition, the multistage centrifugal pump **701** includes two centrifugal pump barrels **730** connected in series by a high pressure interconnecting manifold **709**. In this embodiment, each pump barrel **730** contains **76** impellers having a diameter of approximately 5-11 inches. An example of such a pump barrel **730** is

commercially available from Reda Pump Co. of Singapore (i.e., a Reda series 862 HM520AN HPS pump barrel with 76 stages.)

In one embodiment, the prime mover **706** in each multistage centrifugal pump **701** in the pump system **700** of FIG. **7** is an electric motor with a maximum rating of 3500 brake horsepower, which when accounting for losses (typically about 30% for multistage centrifugal pumps in hydraulic fracturing operations), allows each clean pump **701** in the pump system **700** of FIG. **7** to supply a maximum of about 2450 hydraulic horsepower to the fracturing fluid. Therefore, in order to supply 10,000 hydraulic horsepower to a fracturing fluid, assuming each dirty pump **301'** supplies about 1000 hydraulic horsepower to the fracturing fluid (as assumed in the pump systems **200** and **300** of FIGS. **2** and **3**), the pump system **700** of FIG. **7** would require four multistage centrifugal pumps **701** each supplying 2450 hydraulic horsepower in order to obtain a total of about 11,880 hydraulic horsepower.

Note that the excess available 1,880 hydraulic horsepower over the required 10,000 hydraulic horsepower allows one of the pumps **701/301'** in the pump system **700** of FIG. **7** to fail with the remaining pumps **701/301'** making up for the absence of the failed pump, and/or allows the clean pumps **701** to operate at less than full power. Note, however, that since the multistage centrifugal pumps **701** of FIG. **7** do not contain a transmission, they can be run at full power without fear of failure. As such, in order for the pump system **700** of FIG. **7** to pump the same concentration of proppant at the same hydraulic horsepower as the pump system **200** of FIG. **2**, four less total pumps are required. In addition, the clean pumps **701** in the pump system **700** of FIG. **7** are likely to last longer than the pumps **201** in the pump system **200** of FIG. **2**.

FIG. **9** shows an embodiment similar to that shown in FIG. **5**, but with yet another configuration of clean pumps **901**. Note that many portions of the pump system **900** of FIG. **9** may generally operate in the same manner as described above with respect to the pump system **300** of FIG. **3**. Therefore, the operations of the pump system **900** of FIG. **9** that are similar to the operations described above with respect to the pump system **300** of FIG. **3** are not repeated here to avoid duplicity. However, as mentioned above, a difference between the pump system **900** of FIG. **9** and the pump system **300** of FIG. **3** is that the clean pumps **901** on the clean side **305** of the pump system **900** of FIG. **9** are multistage centrifugal pumps rather than plunger pumps. In addition, although the clean pumps **501/901** in the pump systems **500/900** of both FIGS. **5** and **9** are multistage centrifugal pumps, the multistage centrifugal pumps in the pump system **900** of FIG. **9** are configured differently than the multistage centrifugal pumps of FIG. **5**.

For example, in the embodiment of FIG. **9**, each clean pump **901** may have the same or a similar configuration as the multistage centrifugal pump **901** shown in FIG. **10**. As shown in FIG. **10**, the multistage centrifugal pump **901** is mounted on a standard trailer **102** for ease of transportation by a tractor **104**. The multistage centrifugal pump **901** includes a prime mover **906** that drives the impellers contained therein through a gearbox **911**. In addition, the multistage centrifugal pump **901** includes two centrifugal pump barrels **930** connected in series by a high pressure interconnecting manifold **909**. In this embodiment, each pump barrel **930** contains **76** impellers having a diameter of approximately 5-11 inches. An example of such a pump barrel **930** is commercially available from Reda Pump Co. of Singapore (i.e., a Reda series 862 HM520AN HPS pump barrel with 76 stages.)

In one embodiment, the prime mover **906** in each multistage centrifugal pump **901** in the pump system **900** of FIG. **9** is a turbine engine with a maximum rating of 3500 brake horsepower, which when accounting for losses (typically about 30% for multistage centrifugal pumps in hydraulic fracturing operations), allows each clean pump **901** in the pump system **900** of FIG. **9** to supply a maximum of about 2450 hydraulic horsepower to the fracturing fluid. Therefore, in order to supply 10,000 hydraulic horsepower to a fracturing fluid, assuming each dirty pump **301'** supplies about 1000 hydraulic horsepower to the fracturing fluid (as assumed in the pump systems **200** and **300** of FIGS. **2** and **3**), the pump system **900** of FIG. **9** would require four multistage centrifugal pumps **901** each supplying 2450 hydraulic horsepower to obtain a total of about 11,880 hydraulic horsepower.

Note that the excess available 1,880 hydraulic horsepower over the required 10,000 hydraulic horsepower allows one of the pumps **901/301'** in the pump system **900** of FIG. **9** to fail with the remaining pumps **901/301'** making up for the absence of the failed pump, and/or allows the clean pumps **901** to operate at less than full power. However, note that since the multistage centrifugal pumps **901** of FIG. **9** do not contain a transmission, they can be run at full power without fear of failure. As such, in order for the pump system **900** of FIG. **9** to pump the same concentration of proppant at the same hydraulic horsepower as the pump system **200** of FIG. **2**, four less total pumps are required. In addition, the clean pumps **901** in the pump system **900** of FIG. **9** are likely to last longer than the pumps **201** in the pump system **200** of FIG. **2**.

Note, in each of the embodiments of FIGS. **5**, **7** and **9**, the pump barrels **530/730/930** are shown connected in series, however, in alternative embodiments the pump barrels **530/730/930** in any of the embodiments of FIGS. **5**, **7**, and **9** may be connected in parallel, or in any combination of series and parallel. However, an advantage of having the barrels **530/730/930** arranged in a series configuration is that the fluid leaves each successive barrel **530/730/930** at a higher pressure, whereas in a parallel configuration the fluid leaves each barrel **530/730/930** at the same pressure.

Progressing cavity pumps have characteristics very similar to multistage centrifugal pumps, and therefore may be desirable for use in pump systems according to the present invention. FIG. **11** shows an example of a progressing cavity pump **1140**. As shown, the progressing cavity pump **1140** receives a fluid through an intake pipe **1142** at a low pressure and discharges it through a discharge pipe **1144** at a high pressure by passing the fluid along a long cylindrical pipe or barrel **1130** having a series of twists **1146** (also referred to as turns or stages). That is, as the fluid is propelled by each successive twist **1146**, it gains more and more pressure until it exits the pump **1140** at a much higher pressure than it entered. To create a progressing cavity pump with a greater pressure output, the diameter of the twists **432** may be increased and/or the number of twist **432** (also referred to as the number of stages of the pump) may be increased. Suitable progressing cavity pumps for oilwell operations, such as hydraulic fracturing operations, include the Moyno 962ERT6743, and the Moyno 108-T-315, among other appropriate pumps.

As such, in any of the embodiments described above, the clean pumps **301** may be replaced with progressing cavity pumps. In addition, progressing cavity pumps are capable of handling very high solids loadings, such as the proppant concentrations in typical hydraulic fracturing operations. Consequently, in any of the embodiments described above, the dirty pumps **301'** may be replaced with progressing cavity pumps. In addition, in any of the embodiments described above, the clean pumps **301** may include any combination of plunger pumps, multistage centrifugal pumps and progressing cavity pumps; and the dirty pumps may similarly include

any combination of plunger pumps, multistage centrifugal pumps and progressing cavity pumps.

Note also that in each of the above pump system embodiments **200/300/500/700/900** it was assumed that the accompanying well **120** required 10,000 hydraulic horsepower. This was assumed so that each of the pump systems **200/300/500/700/900** could be directly compared to each other. However, in each of the pump systems **300/500/700/900** described above the total output hydraulic horsepower may be increased/decreased by using a prime mover **106/506/706/906** with a larger/smaller horsepower output, and/or by increasing/decreasing the total number of pumps in the pump system **300/500/700/900**. With these modifications, each of the pump systems **300/500/700/900** described above may supply a hydraulic horsepower in the range of about 500 hydraulic horsepower to about 100,000 hydraulic horsepower, or even more if needed.

In various embodiments, the prime mover **106/506/706/906** in any of the above described pump systems **300/500/700/900** may be a diesel engine, a gas turbine, a steam turbine, an AC electric motor, a DC electric motor. In addition, any of these prime movers **106/506/706/906** may have any appropriate power rating.

FIG. **12** shows another embodiment of a pump system **1200** according to the present invention wherein the fluid to be pumped (such as a fracturing fluid) is split into a clean side **305** containing primarily water that is pumped by one or more clean pumps **1201**, and a dirty side **305'** containing solids in a fluid carrier (for example, a proppant in a gelled water) that is pumped by one or more dirty pumps **1201'**.

In the embodiment of FIG. **12**, the clean side pumps **1201** may operate in the same manner as any of the embodiments for the clean side pumps **301/501/701/901** described above, and therefore may contain one or more plunger pumps **301**; one or more multistage centrifugal pumps **501/701/901**; one or more progressing cavity pumps **1140**; or any appropriate combination thereof. Similarly, the dirty side pumps **1201'** may operate in the same manner as any of the embodiments of the dirty side pumps **301'** described above, and therefore may contain one or more plunger pumps **301**; one or more multistage centrifugal pumps **501/701/901**; one or more progressing cavity pumps **1140**; or any appropriate combination thereof.

However, in contrast to the embodiments disclosed above, in the pump system **1200** of FIG. **12**, the clean side pumps **1201** may be remotely located from the dirty side pumps **1201'/1201"**. In addition, the clean side pumps **1201** may be used to supply a clean fluid to more than one wellbore. For example, in the embodiment of FIG. **12**, the clean side pumps **1201** are shown remotely located from, and supplying a clean fluid to, the wellbores **1222** and **1222'** of both a first well **1220** and a second well **1220'**. Such a configuration significantly reduces the required footprint in the area around the wells **1218** and **1218"** since only one set of clean side pumps **1201** is used to treat both wellbores **1222** and **1222"**.

However, it should be noted that in alternative embodiments, the clean side pumps **1201** may be remotely connected to a single well, or remotely connected to any desired number of multiple wells, with each of the multiple wells being either directly connected to one or more dedicated dirty side pumps or remotely connected to one or more remotely located dirty side pumps. In addition, in further embodiments, one or more dirty pumps may be remotely connected to a single well or remotely connected to any desired number of multiple wells. Also, the well treating lines **1250** and **1250"** used to connect the pumps **1201/1201'/1201"** to the wellbores **1222/1222"** may be used as production lines when it is desired to produce the well. In one embodiment, the clean side pumps **1201** may be remotely located by a distance anywhere in the range of about one thousand feet to several miles from the well(s) **1201/1201'** to which they supply a clean fluid.

Although the above described embodiments focus primarily on pump systems that use dirty pumps to pump a fracturing fluid during a hydraulic fracturing operation, in any of the embodiments of the pump systems described above the dirty pumps may be used to pump any fluid or gas that may be considered to be more corrosive to the dirty pumps than water, such as acids, petroleum, petroleum distillates (such as diesel fuel), liquid Carbon Dioxide, liquid propane, low boiling point liquid hydrocarbons, Carbon Dioxide, an Nitrogen, among others.

In addition, the dirty pumps in any of the embodiments described above may be used to pump minor additives to change the characteristics of the fluid to be pumped, such as materials to increase the solids carrying capacity of the fluid, foam stabilizers, pH changers, corrosion preventers, and/or others. Also, the dirty pumps in any of the embodiments described above may be used to pump solid materials other than proppants, such as particles, fibers, and materials having manufactured shapes, among others. In addition, either the clean or the dirty pumps in any of the embodiments described above may be used to pump production chemicals, which includes any chemicals used to modify a characteristic of the well formation of a production fluid extracted therefore, such as scale inhibitors, or detergents, among other appropriate production chemicals.

The preceding description has been presented with reference to presently preferred embodiments of the invention. Persons skilled in the art and technology to which this invention pertains will appreciate that alterations and changes in the described structures and methods of operation can be practiced without meaningfully departing from the principle, and scope of this invention. Accordingly, the foregoing description should not be read as pertaining only to the precise structures described and shown in the accompanying drawings, but rather should be read as consistent with and as support for the following claims, which are to have their fullest and fairest scope.

The invention claimed is:

1. A method of pumping an oilfield fluid from a well surface to a wellbore comprising:

providing a clean stream comprising water sourced from water tanks, wherein the clean stream contains primarily water;

operating one or more clean pumps to pump the clean stream from the well surface to the wellbore;

providing a dirty stream comprising a solid material disposed in a fluid carrier comprising the water sourced from water tanks, wherein the fluid carrier comprises a gelling agent;

operating one or more dirty pumps to pump the dirty stream from the well surface to the wellbore; and

combining, at the well surface, the clean stream and the dirty stream in a common manifold to form the oilfield fluid, and pumping the oilfield fluid to the wellbore.

2. The method of claim **1**, wherein each of the one or more clean pumps is a first type of pump and each of the one or more dirty pumps is a second type of pump, and wherein the first type of pump is a same type of pump as the second type of pump.

3. The method of claim **2**, wherein the first type of pump and the second type of pump are each plunger pumps.

4. The method of claim **1**, wherein each of the one or more clean pumps is a first type of pump and each of the one or

more dirty pumps is a second type of pump, and wherein the first type of pump is a different type of pump as the second type of pump.

5. The method of claim 4, wherein the first type of pump is a multistage centrifugal pump and the second type of pump is a plunger pump.

6. The method of claim 4, wherein the first type of pump is a progressing cavity pump and the second type of pump is a plunger pump.

7. The method of claim 1, wherein each of the one or more clean pumps is a multistage centrifugal pump.

8. The method of claim 1, wherein each of the one or more clean pumps is a progressing cavity pump.

9. The method of claim 1, wherein each of the one or more clean pumps is a plunger pump.

10. The method of claim 1, wherein the one or more clean pumps comprise any of one or more multistage centrifugal pumps, one or more progressing cavity pumps and one or more plunger pumps.

11. The method of claim 1, wherein each of the one or more dirty pumps is a progressing cavity pump.

12. The method of claim 1, wherein each of the one or more dirty pumps is a plunger pump.

13. The method of claim 1, wherein the one or more dirty pumps comprise any of one or more multistage centrifugal pumps, one or more progressing cavity pumps and one or more plunger pumps.

14. The method of claim 1, wherein each of the one or more clean pumps comprises a prime mover for supplying power, and wherein the prime mover is chosen from the group consisting of a diesel engine, a gas turbine, a steam turbine, an AC electric motor, and a DC electric motor.

15. The method of claim 1, wherein the one or more clean pumps are disposed remotely from the wellbore.

16. The method of claim 1, wherein the solid material is a proppant and wherein the oilfield fluid is a fracturing fluid.

17. The method of claim 1, wherein the solid material is one of a particle, a fiber and a material having a manufactured shape.

18. The method of claim 1, wherein the dirty stream further comprises one of an additive to change the characteristics of the oilfield fluid and a production chemical.

19. The method of claim 1, wherein the manifold is disposed upstream of the wellbore.

20. A method of pumping an oilfield fluid from a well surface to a plurality of wellbores, wherein the plurality of wellbores comprises at least a first wellbore and a second wellbore, the method comprising:

providing a clean stream;

operating one or more clean pumps to pump the clean stream from the well surface to both the first wellbore and the second wellbore;

providing a first dirty stream comprising a first solid material disposed in a first fluid carrier; and

operating one or more first dirty pumps to pump the first dirty stream from the well surface to the first wellbore, wherein the clean stream and the first dirty stream together form said oilfield fluid;

providing a second dirty stream comprising a second solid material disposed in a second fluid carrier; and

operating one or more second dirty pumps to pump the second dirty stream from the well surface to the second wellbore, wherein the clean stream and the second dirty stream together form said oilfield fluid.

21. The method of claim 20, wherein the one or more clean pumps are remotely located from the first wellbore.

22. The method of claim 20, wherein the one or more clean pumps are remotely located from both the first wellbore and the second wellbore.

23. The method of claim 20, wherein the first solid material and the second solid material is a proppant and wherein the oilfield fluid is a fracturing fluid.

24. A method of pumping an oilfield fluid from a well surface to a wellbore comprising:

providing a clean stream comprising water sourced from water tanks, wherein the clean stream contains primarily water;

operating one or more clean pumps to pump the clean stream from the well surface to the wellbore;

providing a dirty stream comprising a corrosive material and the water sourced from water tanks, wherein the fluid carrier comprises a gelling agent;

operating one or more dirty pumps to pump the dirty stream from the well surface to the wellbore; and

combining, at the well surface, the clean stream and the dirty stream in a common manifold to form the oilfield fluid.

25. The pump system of claim 24, wherein each of the one or more clean pumps comprises any of one or more multistage centrifugal pumps, one or more progressing cavity pumps and one or more plunger pumps; and wherein each of the one or more dirty pumps comprises any of one or more multistage centrifugal pumps, one or more progressing cavity pumps and one or more plunger pumps.

26. The method of claim 24, wherein the manifold is disposed upstream of the wellbore.

27. The method of claim 24, wherein each of the one or more clean pumps is a plunger pump and each of the one or more dirty pumps is plunger pump.

28. The method of claim 24, wherein each of the one or more clean pumps is a multistage centrifugal pump and each of the one or more dirty pumps is plunger pump.

29. The method of claim 24, wherein each of the one or more clean pumps comprises a prime mover for supplying power, and wherein the prime mover is chosen from the group consisting of a diesel engine, a gas turbine, a steam turbine, an AC electric motor, and a DC electric motor.

30. The method of claim 24, wherein the one or more clean pumps are disposed remotely from the wellbore.

31. The method of claim 24, wherein the corrosive material is chosen from the group consisting of acids, petroleum, petroleum distillates, liquid Carbon Dioxide, liquid propane, low boiling point liquid hydrocarbons, Carbon Dioxide, and Nitrogen.

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